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EXPERIMENTAL INVESTIGATION AND DESIGN OPTIMIZATION OF FACE MILLING PARAMETERS ON MONEL K-500 BY DOE CONCEPT

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ABSTRACT

K-Monel 500 is a precipitation hardenable, Nickel copper alloy with corrosion resistance. Typical applications for Monel K-500 include fasteners, springs, chain, pump, Impeller and Valve components due their excellent Mechanical properties. The continuous development of carbide milling cutter and its coating technology are great concern with manufacturing Environment. cBN coating milling cutter play vital role in milling cutter, to produce better surface finish and tool life with minimum cost. In this paper deals investigation of face milling operation of Monel K-500 plates with different process parameters like spindle speed, feed rate and depth of cut and to find optimal machining conditions of minimum surface roughness(Ra) has been predicted. The experiments are designed and conducted based on Taguchi's design of Experiments using L_{27} orthogonal array and analyzed by ANOVA.

KEYWORDS: Face Milling, Monel, Milling Parameters, Surface Roughness & Optimization

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Original Article

INTRODUCTION

Milling process is one of the common metals cutting operations and especially used for making complex shapes and finishing of machined parts. The quality of the surface plays a very important role in the performance of the milling as a good quality milled surface significantly improves fatigue strength, corrosion resistance or creep life. Vijaya Krishna Teja et al. [1] conducted an experimental study on performance characteristics of AISI 304 stainless steel during CNC milling process. This research work represents multi-objective optimization of face milling process parameters using Grey-Taguchi method in machining of AISI 304 stainless steel. Sanjit Moshat et al. [2] studied the highlights of optimization of CNC end milling process parameters to provide good surface finish as well as high material removal rate (MRR). Yang et al [3] applied the design of experiments approach to optimize machining parameters of hardened materials under dry machining in end milling. Ozcelik and Mahmud [4] discussed about the importance of surface roughness for any machining operation. Zhang et al[6] used taguchi design, to optimize surface quality in a CNC face milling operation. El-Sonbaty. I. A and Khashaba. U.A et al [5] used artificial neural network and fractal geometry approach, to predict surface roughness profiles for milled surfaces. Che-Haron and Jawaid et al [6] studied the effect of machining on surface integrity of titanium. Ding et

al [7] experimentally investigated the effects of cutting parameters on cutting forces and surface roughness in hard milling of AISI H13 steel with coated carbide tools. Aslan [8] informed that face milling of AISI D3 steel at 62 HRc and found that the best cutting performance in terms of flank wear and surface finish was reached by polycrystalline cubic boron insert tools (cBN), which were capable of removing material volume of 65 $cm^3$and generated a surface finish of Ra between 0.3 and 3µm for a flank wear up to 300 µm and with one single insert (z=1). Ceramic tools, made of aluminium oxide (Al_20_3),were capable of removing less material volume (8 cm^3) and reaching a surface roughness R between 1.3 to 3µm, for a flank wear up to 300 µm, but both tools caused a rapid deterioration of the work piece surface in the final stage of tool life. Oshy et al. tested face milling of AISI D2 hardened steel, at 58 HRC with a round cBN insert and found acceptable tool life (43 cm of removed material) together with excellent surface finish in the range of 0.1 to 0.2µm in Ra. Braghini and Coelho tested a cBN insert (z=1) to face mill AISI D6 hardened steel at 58 HRC, removing 15 cm^3 of material with 300µm of tool wear. In this case, surface finish was between 0.2 and 0.3 µm in Ra. Conclusions of these two experimental works point out that tool life would need to be extended to make the process economically viable. Since the fact that cBN tools are still very expensive and are difficult to find with complex shapes for better finishing performance, it is proposed in our study the use of geometrically complex inserts made of PVD AlCrN coated tungsten carbide. Based on the literature review and shows work piece material, hardness, cutting tool material, process factors and related responses were used this study. Experiment also carried out in Design of Experiments to investigate the influence of cutting parameters such as cutting speed, feed rate and depth of cut on surface roughness in face milling operation. Taguchi parameter design which provides a systematic procedure that can effectively and efficiently identify the optimum surface roughness in the process control of individual end milling machines. A series of experiment have been carried out in Design of Experiments to investigate the influence of cutting conditions such as cutting speed, feed rate per tooth, feed velocity on tool life, tool wear and surface finish in face milling operation investigated the machining parameters such as, number of passes, depth of cut in each pass, spindle speed and feed rate to get better surface finish, dimensional accuracy and tool wear also investigated. A series of experiment have been carried out in Taguchi's parametric design in which signal to noise ratio and Pareto analysis of variance are employed to analyze the effect of milling parameters such as cutting speed, feed rate and depth of cut on surface roughness. Grey-Taguchi parameter method wear used to optimize the milling parameters to get better surface finish. There are relatively few researches related to surface roughness with using side and face milling cutter in hardened steel. [8] Zhang et al. used Taguchi design of optimization to predict surface roughness CNC milling operation. El-Sonbaty et al used artificial neural networks and traced geometry approach to predict the surface roughness profile milling operations. Several researchers have studied the effect of cutting conditions in machining of nickel based super alloys [9, 10, 11, and 12]. Most of the research on machining Inconel alloy is concentrated mainly on the study of cutting tool wear and wear mechanism [12, 13]. Poor selection of machining parameters causes cutting tools to wear and break quickly as well as economical losses such as damaged work-piece and poor surface quality [13, 15]. Among various machining processes, the end-milling process is one of the most widely used material removal processes in industry. The cutting operations by the end mills can be as simple as a face milling on the top of a flat surface with a rigid cutter or a milling of very complex parts [16] All the above researcher conducted milling operation in Hard steel and Inconol, but no one has conducted experiment on Monel K-500.

EXPERIMENTAL SET-UP

The experiments conducted in HMT make Universal milling machine using cBN coated milling cutter with various spindle speed, feed rate and depth of cut on Monel K-500, experiments are designed by Taguchi L_{27} orthogonal

array and analyzed by Signal to noise ratio and Analysis of variance.

Table 1: Levels and Factors of Face Milling Process on Monel K-500

Sl. No	Levels	Spindle Speed	Feed Rate	Depth of Cut
1	Low	900	0.030	0.2
2	Medium	1200	0.025	0.4
3	High	1500	0.020	0.6

Table 2: Chemical Composition of Monel K-500

Ni	Cu	Al	Ti	C	Mn	Fe	Si
70	24	2.0	0.8	0.25	1.04	2.05	0.50

Table 3: Mechanical Properties of Monel K-500

Tensile Strength (Ksi)	Elongation (%)	Hardness (HRc)	Fatigue (Ksi)
180	30	35	43

Taguchi Design of Experiments

The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic the general steps involved in the Taguchi Method are as follows:

- Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum; for example, the goal may be to maximize the output flow rate. The deviation in the performance characteristic from the target value is used to define the loss function for the process.
- Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified.
- Create orthogonal arrays for the parameter design indicating the number of conditions for each experiment.
- Conduct the experiments indicated in the orthogonal array to collect data on the effect on the performance measure.
- Complete data analysis to determine the effect of the different parameters on the performance measure.

ANOVA

Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes *t*-test to more than two groups. Doing multiple two-sample t-tests would result in an increased chance of committing a type I error. ANOVAs are useful in comparing two, three, or more means. The fundamental technique is a

partitioning of the total sum of squares *SS* into components related to the effects used in the model.

RESULTS AND DISCUSSIONS

Face milling operation has been in conducted HMT Universal Milling Machine with different milling parameters using cBN coated milling cutter. In this experimental work L 27 taguchi design of experiments are used to conduct in 3 levels and 3 factors are designed by orthogonal array. The milling machine has allowed to machining super alloy material of Monel K-500 with coated milling cutter of cBN, with different milling process parameters. After the milling process surface roughness of specimen are measured by Surface roughness meter and corresponding values are enter in L 27 (Table 4) orthogonal array design. Smaller is the better concept is used to analyze the signal to noise ratio of surface roughness. It represent lower surface roughness was obtained in 1500 rpm of spindle speed,0,020 mm/rev of feed rate and 0.4 mm of Depth of cut.

Table 4: Face Milling Process Parameters on (L_{27}) Monel K-500 Plates

Test No	Spindle Speed (RPM)	Feed Rate (mm/rev)	Depth of Cut mm)	Surface Roughness (Micron)
1	900	0.030	0.2	2.90
2	900	0.030	0.2	2.68
3	900	0.030	0.2	2.76
4	900	0.025	0.4	2.88
5	900	0.025	0.4	2.78
6	900	0.025	0.4	2.64
7	900	0.020	0.6	2.34
8	900	0.020	0.6	2.12
9	900	0.020	0.6	2,14
10	1200	0.030	0.4	2.80
11	1200	0.030	0.4	2.84
12	1200	0.030	0.4	2.56
13	1200	0.025	0.6	2.42
14	1200	0.025	0.6	2.40
15	1200	0.025	0.6	2.52
16	1200	0.020	0.2	2.78
17	1200	0.020	0.2	1.90
18	1200	0.020	0.2	1.24
19	1500	0.030	0.6	1.22
20	1500	0.030	0.6	1.26
21	1500	0.030	0.6	1.20
22	1500	0.025	0.2	1.18
23	1500	0.025	0.2	1.16
24	1500	0.025	0.2	1.11
25	1500	0.020	0.4	1.24
26	1500	0.020	0.4	1.12
27	1500	0.020	0.4	1.10

Table 5: Response Table for Face Milling Process

Level	Spindle Speed	Feed Rate	Depth of Cut
1	-8.196	-6.468	-5.468
2	-7.614	-5.938	-6.280
3	-1.407	-4.812	-5.469
Delta	6.789	1.656	0.811
Rank	1	2	3

Table 5 represents the spindle speed (Rank-1) is an influence parameter for while achieving lower surface

roughness of Face milling process on Monel K-500 plates from different milling process parameters & analyzed by signal to noise values. It indicate Monel K 500 provided 70 % nickel and 24% 0f copper which lead to high hardness(35 HRc), so it need high spindle speed with coated milling cutter(cBN) for producing lower surface roughness for achieving High quality of products. It also represent Depth of cut is not a significant factor of surface roughness of Monel K-500 grade material.

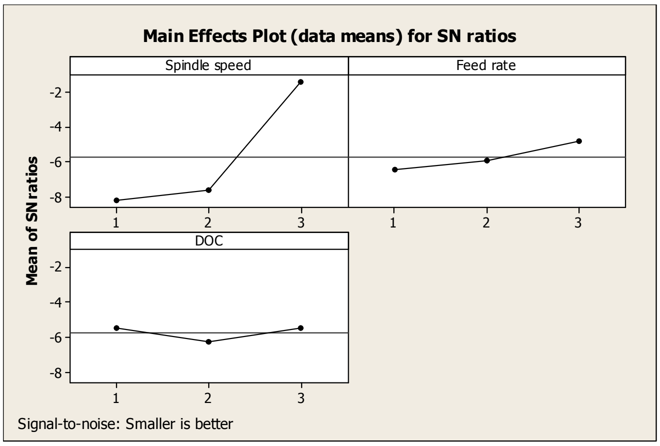

Figure 2: Main Effect Plot of Face Milling Process of Monel K-500 plates

Figure 2 shows that graphical representation of Face milling process parameters of Monel K-500 plates which denotes lower surface roughness is obtained in high level spindle speed, high level of feed rate and medium level of depth of cut based on signal to noise ratio values. The controllable parameters such as spindle speed, feed rate and depth of cut are set by machine tool which relate with uncontrollable parameter such as tool vibrations, Machine vibrations, coolant and atmosphere in machining process are arrived by S/N ratio which mention through main effects plot for achieving lower surface roughness of Monel K-500 material.

Table 6

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Spindle speed	2	10.4	10.43	5.218	72.5	0.0	78.24
Feed rate	2	1.06	1.069	0.534	7.43	0.0	8.02
Depth of Cut	2	0.39	0.392	0.196	2.72	0.0	2.94
Error	20	1.43	1.43	0.072	--	--	10.9
Total	**26**	**--**	**--**	**--**	**--**	**--**	**100**

Table 5 shows that ANOVA values of face milling process which maximum values of F Test denote the optimum parameter of achieving lower surface roughness. It indicate spindle speed is a dominating parameter of Face Milling process of Monel K-500 plates which contribute 78.24 % using cBN coated milling cutter. Normally Monel K-500 provided high fatigue resistane (43%) which play an important role to produce lower surface roughness with high spindle speed. In Mathematically R-square value (97.56%) confirm the optimum parameter of face milling process. cBN milling cutter is suitable machining Monel K-500 and provide good mach inability property.

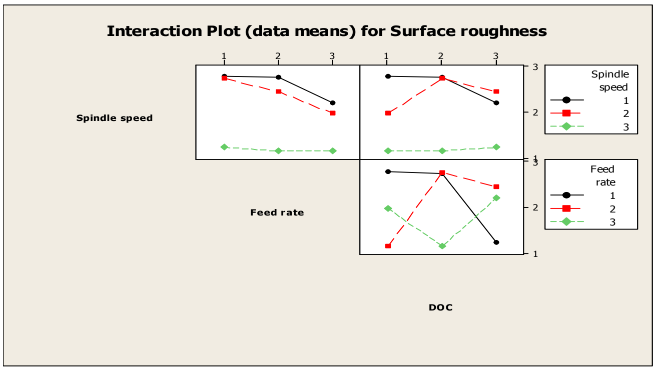

Figure 3: Interaction Plot for Face Milling Process of Monel K-500

Figure 3 shows that interaction plot for Face milling operation using cBN coated face milling cutter. It represents level 1(900 rpm) and level 2 (1200rpm) of spindle speed, Level 1 (0.030 mm/rev) level 2 (0.025 mm/rev) of feed rate and all levels (0.2mm,0.4mm and 0.6 mm) of depth cut are dependable parameter of Face milling process and produce Lower surface roughness. The interaction plot also mention the relation between milling parameters which influence lower surface roughness while machining Monel K -500 using cBN milling cutter.

CONCLUSIONS

After performing 27 experiments of Face milling process on Monel K-500 using cBN coated milling cutter, the following conclusions are derived:

- Spindle speed and feed rate are most influencing parameters in Face milling operation.
- Optimum parameter of lower surface roughness is 1500 rpm of Spindle speed, 0.020 mm of feed rate and 0.4 mm of Depth of Cut.
- Depth of cut is not a significant parameter in Face milling process of Monel K-500
- Minimum tool wear occur in cBN coated milling cutter.
- From mathematical calculations Spindle speed of face milling operation process provide 78.24 % of contribution during machining process.
- Monel K-500 provided better machinabilty property and produce good surface finish.

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